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INSULATED GATE SEMICONDUCTOR DEVICE  
AND  
METHOD OF MANUFACTURING THE SAME

Ins. A' >

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the structure of an insulated gate semiconductor device formed using a crystalline semiconductor substrate, for example, a monocrystal silicon substrate or an SOI substrate (SIMOX or the like), and more particularly to the structure of an insulated gate field effect transistor (hereinafter referred to simply as "IG-FET") and a method of manufacturing the same. The present invention relates to a technique of which advantages are especially exhibited in the case of manufacturing a fine device whose channel length is 1  $\mu\text{m}$  or less (representatively, 0.01 to 0.35  $\mu\text{m}$ ).

Therefore, the present invention is applicable to a semiconductor integrated circuit such as an IC, a VLSI or a ULSI, which is structured with integrated IG-FETs.

2. Description of the Related Art

In recent years, integrated circuits such as the VLSI are kept on becoming more fine, and the machining dimensions in the order of a deep sub-micron are required, for example, the width of a wiring is 0.18  $\mu\text{m}$  or less, further 0.1  $\mu\text{m}$  or less.

Up to now, the fining of a semiconductor device is progressed in accordance with the scaling rule, and there has been generally known that the fining leads to an improvement in the characteristic of the integrated circuit. However, the fine machining in the order of the sub-micron suffers from a problem that it does not simply accord to the scaling rule.

The representative problem of this type as known is a phenomenon such as a short channel effect. The short channel effect is the phenomenon caused by the reason that as the line width of a gate electrode is shortened, that is, a channel formation region is shortened the charges in the channel formation region becomes to be largely influenced by not only a gate voltage but also the charges in a depletion layer of a source/drain region, an electric field and a potential distribution.

This state is simplified and shown in Fig. 3. Reference numeral 301 denotes a source region, reference numeral 302 denotes a drain region, reference numeral 303 denotes a channel region, and reference numeral 304 denotes a gate electrode. Also, a dotted line indicated by reference numeral 305 represents a depletion layer which is formed when a drain voltage  $V_d$  is small.

Normally, a current that flows in the channel region 303 is controlled by only a gate voltage  $V_g$ . In this case, as indicated by reference numeral 305, since the depletion layer which is in the vicinity of the channel region 303 is

substantially in parallel with the channel, a uniform electric field is formed.

However, as the drain voltage  $V_d$  becomes high, the depletion layer which is in the vicinity of the drain region 302 is expanded toward the channel region 303 and the source region 301, with the result that as indicated by a solid line 306, the charge and the electric field in the drain depletion layer become to influence the depletion layer which is in the vicinity of the source region 301 and the channel region 303. In other words, an on-state current is changed according to a complicated electric field distribution, thereby making it difficult to control the current which flows in the channel region 303 by only the gate voltage  $V_g$ .

Here, an energy state in the periphery of the channel formation region when the short channel effect occurs will be described with reference to Fig. 4. In Fig. 4, state graphs indicated by solid lines represent energy bands of the source region 401, the channel formation region 402 and the drain region 403, respectively, when the drain voltage is 0 V.

In this state, when the drain voltage  $V_d$  which is sufficiently large is applied, the energy bands are changed into the states indicated by dotted lines in Fig. 4. In other words, the depletion charges and the electric field in the drain region 103 which are formed by the drain voltage  $V_d$  influence the charges in the depletion layers of the source and channel regions 401 and 402 so that an energy (potential)

state is continuously changed from the source region 401 to the drain region 403.

The deterioration of a threshold value voltage ( $V_{th}$ ) and a punch-through phenomenon have been well known as an influence of such a short channel effect on the semiconductor device, for example, the IG-FET. Also, there has been known that a sub-threshold characteristic is deteriorated when an influence of the gate voltage on the drain current by the punch-through phenomenon is lowered.

First, the deterioration of the threshold value voltage is a phenomenon that occurs in an n-channel FET and a p-channel FET, similarly. Also, the degree of the deterioration depends on not only the drain voltage but also a variety of parameters such as the concentration of impurities in a substrate, the depth of source/drain diffusion layer, the thickness of a gate oxide film, a substrate bias and so on.

The deterioration of the threshold value voltage is desirable from a viewpoint of lowering a power consumption, however, there generally arises such a disadvantage that a frequency characteristic is not increased because the drive voltage of the integrate circuit becomes small.

Under that circumstance, up to now, as means for controlling the threshold value voltage, it is general to uniformly add the impurity elements that give one conduction to the entire channel formation region, to control the threshold value voltage with the amount of addition of the

impurity elements. However, even with this method, the short channel effect per se cannot be prevented, and the punch-through phenomenon is caused to occur. Also, since the added impurities allow carriers to be scattered, the mobility of carriers is caused to be lowered.

Also, the deterioration of the sub-threshold characteristic which is accompanied by the punch-through phenomenon means that the sub-threshold coefficient (S value) is increased, that is, the switching characteristic of an FET is deteriorated. An influence of the short channel effect on the sub-threshold characteristic is shown in Fig. 5.

Fig. 5 is a graph taking the gate voltage  $V_g$  in a horizontal axis and the logarithm of the drain current  $I_d$  in a vertical axis. The inverse number of a slope (sub-threshold characteristic) in the region 501 is an S value. In Fig. 5, the changes of characteristics when gradually shortening the channel length are compared, and the channel length is shortened toward a direction indicated by an arrow.

As a result, there can be confirmed that the slope of the characteristic is decreased, that is, the S value is tended to be increased with the channel length being shortened. This means that the switching characteristic of the FET is deteriorated with the channel length being shortened.

The above-description is made to the short channel effect in the case of extremely shortening the length of the

channel formation region of the semiconductor device. In the case of extremely narrowing the width of the channel formation region, the phenomenon such as the narrow channel effect also occurs.

What is shown in Fig. 6 is a cross-sectional view showing a normal IG-FET being cut on a plane perpendicular to the channel direction (a direction connecting the source and the drain). Reference numeral 601 denotes a monocrystal silicon substrate, and reference numeral 602 denotes a field oxide film formed through the selectively oxidizing method. The respective semiconductor devices used in the VLSI are separated by the field oxide film 602, respectively.

Also, reference numeral 603 denotes a gate electrode to which a voltage is applied to form a channel region 604. Impurity region 605 is disposed below the field oxide film 602 and functions as a channel stopper.

The narrow channel effect is caused in such a manner that a bird beak portion is which is an intrusion of the field oxide film 602 and the impurity region 605 into the channel region 604 largely influences the channel region 604 as the channel width  $W$  is narrowed. In particular, there may be cited an increase in the threshold value voltage and a dependency of the effective channel width on a supply voltage.

In the existing semiconductor industry, a semiconductor integrated circuit which has been integrated up to the limit has been demanded, and it is important to which

degree the fining of the respective semiconductor devices can be pursued. However, even if a technique to form a fine pattern in the order of the deep sub-micron is developed, the problem of the above-mentioned short channel effect leads to a fatal obstacle that obstructs the fining of the device.

#### SUMMARY OF THE INVENTION

The present invention has been made in view of the above circumstances, and therefore an object of the present invention is to provide a technique for effectively restraining the short channel effect accompanied by the fining of the semiconductor device, thereby being capable of forming the fine device in the order of the deep sub-micron which was difficult to realize by the short channel effect.

One structure of the present invention as described in the present specification is featured by comprising:

a source region, a drain region and a channel forming region which are formed using a crystal semiconductor; and

a gate insulating film and a gate electrode formed on said channel forming region;

wherein said channel forming region includes a region in which carriers move, and an impurity region which pins a depletion layer that expands from said drain region toward said channel forming region and said source region and which is artificially and locally formed.





a gate insulating film and a gate electrode formed on said channel forming region;

wherein said channel forming region includes a region in which carriers move, and an impurity region which pins a depletion layer that expands from said drain region toward said channel forming region and said source region and which is artificially and locally formed; and

wherein impurity elements that expand an energy band width ( $E_g$ ) are added to said impurity region.

Further, another structure of the invention is featured by comprising:

a source region, a drain region and a channel forming region which are formed using a crystal semiconductor; and

a gate insulating film and a gate electrode formed on said channel forming region;

wherein said channel forming region includes a region in which carriers move, and an impurity region which pins a depletion layer that expands from said drain region toward said channel forming region and said source region and which is artificially and locally formed; and

wherein said region in which the carriers move includes means for preventing the impurity scattering of the carriers or means for preventing the deterioration of the mobility which is caused by a factor other than the scattering of a lattice of the carriers.

Further, still another structure of the invention is featured by comprising:

a source region, a drain region and a channel forming region which are formed using a crystal semiconductor; and

a gate insulating film and a gate electrode formed on said channel forming region;

wherein said channel forming region includes a region in which carriers move, and an impurity region which controls the threshold voltage to a predetermined value voltage by the addition of impurity elements and is artificially and locally formed; and

wherein impurity elements that expand an energy band width ( $E_g$ ) are added to said impurity region.

Furthermore, another structure of the invention is featured by comprising:

a source region, a drain region and a channel forming region which are formed using a crystal semiconductor; and

a gate insulating film and a gate electrode formed on said channel forming region;

wherein said channel forming region includes a region in which carriers move, and an impurity region which controls the threshold voltage to a predetermined value voltage by the addition of impurity elements and is artificially and locally formed; and

wherein said region in which the carriers move includes means for preventing the impurity scattering of the

carriers or means for preventing the deterioration of the mobility which is caused by a factor other than the scattering of a lattice of the carriers.

Furthermore, still another structure of the invention is featured by comprising:

a source region, a drain region and a channel forming region which are formed using a crystal semiconductor;

an impurity region artificially and locally provided in said channel forming region by addition of impurity elements that expand an energy band width ( $E_g$ ) in said channel forming region; and

a gate insulating film and a gate electrode formed on said channel forming region;

wherein said impurity region has an insulating property; and

wherein said impurity elements are not added or are added by a very small amount in a region other than said impurity region in said channel forming region.

It should be noted that no addition of impurity elements in a region other than the impurity region or a small amount of addition thereof means that a region (semiconductor layer) where a channel is formed is an intrinsic or substantially intrinsic region.

In the present specification, the intrinsic region is directed to a region to which impurity elements that give n-type or p-type and impurity elements such as carbon, nitrogen



characteristic accompanied by that phenomenon which are problems in the prior art.

Since the IG-FET of the present invention looks like as if pins of an impurity region are formed in the channel forming region, the present applicant calls it "pinning type transistor". In the present specification, "pinning" means "restraint", and "to pin" means "to restrain" or "to suppress".

Also, another subject matter of the present invention is to release by artificially producing the narrow channel effect the deterioration of the threshold value voltage which is a representative phenomenon caused by the short channel effect accompanied by the fining of the channel length.

What is shown in Fig. 1A is a schematic diagram showing states of a source region, a drain region and a channel forming region of a normal IG-FET when being viewed from a top surface thereof. Reference numeral 101 denotes a source region, reference numeral 102 denotes a drain region, and reference numeral 103 denotes a channel forming region.

The feature of the present invention resides in that an impurity region 104 is formed like a dot pattern within the channel forming region 103. In the present invention, as the impurities to be added, there are used one or a plurality of elements selected from carbon (C), nitrogen (N), and oxygen (O).

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The added impurities form an energy barrier which is locally large in an energy band width within the channel forming region 103. In the case of using carbon, nitrogen or oxygen as in the present invention, the energy band which was in a state shown in Fig. 14A becomes a state shown in Fig. 14B, and the energy band width ( $E_g$ ) is widened whereby the barrier  $\Delta E$  further increases to the barrier  $\Delta E'$ . For example, in the case where oxygen is added, it becomes an insulating high-resistant region having a structure represented by  $\text{SiO}_x$ , which forms electrically a barrier.

In particular, as shown in Fig. 1A, since a joint of the drain region 102 and the channel forming region 103 is a region where an electric field is most remarkably changed, it is desirable that the impurity region 104 is disposed at that position. Also, in the case where an electric field caused by the gate electrode reaches the inside of the drain region 102, the impurity region 104 can be formed within the drain region 102. Reversely, it is preferable that no impurity region 104 is formed within the source region 101.

In the above manner, in the case of using carbon, nitrogen or oxygen, since the impurity region is applied as the insulating energy barrier in any cases, it can be commonly used in the n-channel FET and the p-channel FET. This fact means that there is an advantage in simplifying a

manufacturing process when applying the present invention to a CMOS circuit.

Also, there is little risk that those impurity elements are re-diffused by a heat treatment or the like because they are firmly bonded to silicon atoms in the case where a host substrate is made of silicon.

Further, the present invention is extremely effective in forming a fine device that requires the fine machining in the order of the deep sub-micron such as a size of  $0.2\ \mu\text{m}$  or less. Hence, because the length of the channel forming region (the channel length or a distance between the source and the drain) is also shortened to  $0.01$  to  $1.0\ \mu\text{m}$ , representatively,  $0.01$  to  $0.35\ \mu\text{m}$ , the impurity region must be cut into a finer pattern.

For example, in the case of employing a resist mask in forming an impurity region having a dot pattern shape, patterning for forming openings in the resist mask cannot be performed by using a normal exposing method in consideration of a problem regarding the resolution. In such a case, patterning may be performed by using an electron drawing method or an FIB method to realize a fine pattern.

Also, since the dot-pattern shaped impurity region is formed to be artificially arranged by patterning, it can be arranged not only as shown in Fig. 1A but also arbitrarily variously arranged.



Then, a description will be given hereinafter of how to restrain the short channel effect in driving an insulated gate semiconductor device (IG-FET) having the structure of the source region/channel forming region/drain region shown in Fig. 1A.

First, a cross-sectional view taken along a line A-A' of Fig. 1A is shown in Fig. 1B. Reference numeral 105 denotes a field oxide film, and reference numeral 106 denotes a channel stopper. The formation of the impurity region 104 is variable depending on the set conditions, however, a case in which the impurity region is injected in the form of a bar assuming that there is ideally no scattering will be described as an example.

Also, a cross-sectional view taken along a line B-B' of Fig. 1A is shown in Fig. 1C. Reference numeral 107 denotes a field oxide film. Normally, a channel stopper is disposed under the field oxide film, but in this example, it is omitted. The width of the impurity region 104 is indicated by  $W_{pi,n}$ , and its interval is indicated by  $W_{pa,m}$ . In this example,  $n$  and  $m$  means that within the channel forming region 103,  $W_{pi,n}$  is a width of the  $n$ -th impurity region, and  $W_{pa,m}$  is an interval between the  $m$ -th impurity regions (path through which carriers travel).

The above description was made simply to the structure, and its effect will be now described. First, in the case of applying a gate voltage and a drain voltage to a

semiconductor device having a structure shown in Fig. 1B, a source side depletion layer 201, a channel side depletion layer 202 and a drain side depletion layer 203 are formed in a state shown in Fig. 2A. In other words, the drain side depletion layer 203 is prevented from expanding toward the source side by an impurity region 204 to act as a barrier.

Although the present invention is difficult to understand from Fig. 1B, since the impurity region 204 is disposed as shown in Fig. 1A, a model in which a lattice filter that blocks the channel forming region restrains the expansion of the drain side depletion layer facilitates the understanding of the present invention.

Hence, in the semiconductor device having the structure according to the present invention, as shown in Fig. 2A, the depletion layers are divided without being interfered with each other. In other words, since the source side depletion layer 201 and the channel side depletion layer 202 are distributed without being influenced by the drain side depletion layer 203, the energy state becomes a state shown in Fig. 2B.

In other words, since the energy state of the channel region is almost controlled by only an electric field caused by the gate voltage, which is different from the conventional energy state shown in Fig. 5, it has a substantially parallel shape with respect to the channel region. Therefore, with this structure, there arises no problem such as the punch-

through phenomenon inherent to the short channel effect, thereby being capable of structuring a semiconductor device high in drain withstand voltage.

Furthermore, as shown in Fig. 2A, in the present invention, because a volume that occupies the depletion layer is reduced in comparison with the prior art shown in Fig. 3, the present invention has the feature that the charges in the depletion layer are smaller than those of the prior art, and that a capacitor in the depletion layer is small. In this example, an expression that leads an S value is represented by the following expression.

[Expression 3]

$$S = d(V_g) / d(\log I_d)$$

In other words, as described above, it is understandable that the expression represents the inverse number of a slope in the region 501 in the graph shown in Fig. 5. Also, Expression 3 can be approximately represented by the following expression.

[Expression 4]

$$S \approx \ln 10 \cdot kT / q [1 + (C_d + C_{it}) / C_{ox}]$$

In Expression 4, k is the Boltzmann's constant, T is an absolute temperature, q is the amount of charges, C<sub>d</sub> is a capacity of the depletion layer, C<sub>it</sub> is an equivalent capacity of an interfacial level, and C<sub>ox</sub> is a capacity of the gate oxide film. Hence, according to the present invention, since

the capacity  $C_d$  of the depletion layer is sufficiently smaller than that of the prior art, the  $S$  value can be set to a small value of 85 mV/decade or less (preferably, 70 mV/decade or less), that is, an excellent sub-threshold characteristic can be obtained.

Also, the object of the present invention is to allow the capacity  $C_d$  of the depletion layer and the equivalent capacity  $C_{it}$  of the interfacial level to approach 0 as much as possible. In other words, they are allowed to approach an  $S$  value (60 mV/decade) in an ideal state of  $C_d = C_{it} = 0$ .

Further, it is very important that the channel forming region is structured as shown in Fig. 1C for releasing the deterioration of the threshold value voltage which is caused by the short channel effect. This is because the structure shown in Fig. 1C is a structure necessary for intentionally producing a narrow channel effect.

For example, when attention is paid to a cross section shown in Fig. 1C, the width  $W$  of the channel forming region is divided by the impurity region 104 so that it can be substantially regarded as an assembly consisting of a plurality of channel forming regions having a narrow channel width  $W_{pa,m}$ .

In other words, the narrow channel effect can be obtained in the plurality of regions having the narrow channel width  $W_{pa}$ . From the macro viewpoint, since the region where the narrow channel effect is thus obtained exists in the

entire channel forming region as shown in Fig. 1A, it is considered that the narrow channel effect can be obtained as a whole, thus increasing the threshold value voltage.

Hence, even if the threshold value voltage is lowered by the short channel effect which is caused by shortening the channel length, the threshold value voltage is intentionally increased by the narrow channel effect so that the threshold value voltage can be controlled for the above reason, as a result of which a change in the threshold value voltage can be released.

Further, another structure of the invention is featured by comprising the steps of:

forming a source region, a drain region and a channel forming region using a crystal semiconductor;

forming a gate insulating film and a gate electrode on said channel forming region; and

in said channel forming region, forming a region in which carriers move, and an impurity region which pins a depletion layer that expands from said drain region toward said channel forming region and said source region, artificially and locally.

Further, another structure of the invention is featured by comprising the steps of:

forming a source region, a drain region and a channel forming region using a crystal semiconductor;



artificially and locally adding impurity elements that expand an energy band width ( $E_g$ ) to said channel forming region.

Further another structure of the invention is featured by comprising the steps of:

forming a source region, a drain region and a channel forming region using a crystal semiconductor;

forming a gate insulating film and a gate electrode on said channel forming region;

in order to form an impurity region which controls the threshold voltage to a predetermined value voltage by addition of impurity elements and controls a path through which the carriers move, artificially and locally adding impurity elements that expand an energy band width ( $E_g$ ) to said channel forming region.

Further, another structure of the invention is featured by comprising the steps of:

forming a source region, a drain region and a channel forming region using a crystal semiconductor; and

artificially and locally forming an impurity region by addition of impurity elements that expand an energy band width ( $E_g$ ) in said channel forming region; and

forming a gate insulating film and a gate electrode formed on said channel forming region;

wherein said impurity region has an insulating property; and

wherein said impurity elements are not added or are added by a very small amount in a region other than said impurity region in said channel forming region.

#### BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features and advantages of the present invention will become more fully apparent from the following detailed description taken with the accompanying drawings in which:

Figs. 1A to 1C are diagrams showing the structure of a channel forming region;

Figs. 2A and 2B are diagrams showing the structure of the channel forming region;

Fig. 3 is a diagram for explaining a conventional semiconductor device;

Fig. 4 is a diagram showing an energy state of the channel forming region;

Fig. 5 is a graph showing a characteristic of the conventional semiconductor device;

Fig. 6 is a diagram showing the structure of the conventional semiconductor device;

Figs. 7A to 7E are diagrams showing a process of manufacturing an insulated gate field effect transistor;

Figs. 8A to 8C are diagrams for explaining conditions for forming impurity regions;

Figs. 9A and 9B are diagrams for explaining the depthwise shape of the impurity regions;



Figs. 10A to 10C are diagrams for explaining the shape and arrangement of the impurity regions;

Figs. 11A to 11E are diagrams showing the structure of the insulated gate field effect transistor;

Figs. 12A to 12C are diagrams showing a process of manufacturing the impurity regions;

Figs. 13A and 13B are diagrams showing the structure of the insulated gate field effect transistor;

Figs. 14A and 14B are diagrams showing energy states of the channel forming regions;

Fig. 15 is a diagram showing the structure of the channel forming region;

Figs. 16A to 16C are diagrams showing the structure of the channel forming region; and

Fig. 17 is a diagram showing an applied example of the semiconductor device.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Mode of Embodiment of the Invention]

In Figs. 1A to 1C, a region interposed between a source region 101 and a drain region 102 forms a channel forming region 103. In the present invention, impurities are artificially and locally added to the channel forming region 103 to form an impurity region 104.

Also, the impurity region 104 is shaped in a dot pattern and arranged according to a rule. In the present



increase of the threshold value voltage which is caused by the narrow channel effect.

Hereinafter, a description will be given in more detail of preferred embodiments of the present invention with the above structure with reference to the accompanying drawings.

(Embodiment 1)

An example in which an insulated gate electric field effect transistor is formed on a monocrystal silicon substrate in accordance with the present invention will be described with reference to Figs. 7A to 7E. In this embodiment, for simplification of description, there is shown an example in which a single n-channel FET is formed on a p-type silicon substrate.

First, reference numeral 701 denotes a p-type silicon substrate on which a silicon oxide film 702 is formed as a pad oxide film on which a silicon nitride film 703 that functions as a mask which will be used later for selective oxidation is further formed. The thickness of the silicon oxide film 702 and the silicon nitride film 703 may be 500 to 2000 Å (Fig. 7A).

Then, patterning is conducted so that the silicon nitride film 703 remains only in the device formation region, and in this state, ions of impurity elements that give p-type conduction are implanted into the silicon nitride film 703.



designed such that holes are defined in a resist not shown through patterning.

It should be noted that in order to shape the impurity region 707 in a dot pattern, an extremely fine lithography technique is required. To achieve this, a light shaped in the dot pattern may be exposed using the technique using an electronic beam (electron drawing method) or a technique using an ion beam (FIB method).

In this situation, it is desirable that intervals Wpa, m between the respective impurity regions 707 (refer to Fig. 1C) are made identical with each other. This is because there is a risk that the threshold value voltage is dispersed (which is caused by the dispersion of the narrow channel effect) or heating is dispersed (which is caused by the dispersion of a density of a current that flows between the impurity regions).

After completion of addition of the impurities, a heat oxidizing process is conducted to form a heat oxide film 708 of 100 to 500 Å. The thin heat oxide film 708 formed through heat oxidizing process functions as a gate insulating film as it is.

Furthermore, in the channel forming region 706, a polysilicon film is formed on the oxide film 708 as a gate electrode 709. The impurity elements are added to the polysilicon film in a film forming stage in advance so that the polysilicon film provides conductivity. Thus, a state shown in Fig. 7C is obtained.

Thereafter, as shown in Fig. 7D, impurity elements (P or As) that give n-type conduction are added to form a source region 710 and a drain region 711 in a self aligning manner. Subsequently, a silicon nitride film is formed in thickness of 3000 Å so as to cover the gate electrode 709, and a side wall 712 is allowed to remain only on both side surfaces of the gate electrode 709 by using the etch back method.

Then, a titanium film is formed on the entire surface through the sputtering method in this state, and silicide is formed through means such as heating, laser annealing or lamp annealing. Through this process, titanium silicides 713 to 715 are formed on the surface of the source region 710 and the drain region 711 and on the surface of the gate electrode 709. Since the titanium silicides 713 to 715 are extremely low resistant, it is preferable to ensure those silicides being in ohmic contact with wirings which will be formed later.

After completion of formation of the silicides, a silicon nitride film 716 is formed as an interlayer insulating film, and contact holes are formed therein to form a source electrode 717 and a drain electrode 718. Thus, an IG-FET having a structure shown in Fig. 7E is completed.

The present invention is characterized in that the impurity region is formed in the form of a dot pattern in the channel forming region of the IG-FET. Positions at which the dot pattern is formed are required to satisfy conditions with

a certain limit. This will be described with reference to Fig. 8.

In Fig. 8, reference numeral 801 denotes a part of the channel forming region, where the channel width is indicated by W. In this example, a width which is occupied by a dot pattern 802 in the channel width W is defined by W<sub>pi</sub>. The value of W<sub>pi</sub> is sufficiently set to, for example, 10 to 100 Å. Also, if the widths of the arbitrary dot pattern 802 are w<sub>pi,1</sub>, w<sub>pi,2</sub>, w<sub>pi,3</sub>, ..... w<sub>pi,n</sub>, then W<sub>pi</sub> is represented by the following expression.

[EXPRESSION 1]

$$W_{pi} = \sum_{n=1}^n w_{pi,n}$$

In order to achieve the structure of the present invention, since it is required that at least one impurity region is formed in a region other than the end portions of the channel forming region, n is an integer of 1 or more.

A width occupied by a region between dot patterns (a path through which carriers move) 803 in the channel width W is defined by W<sub>pa</sub>. The value of W<sub>pa</sub> can be set to, for example, 100 to 3000 Å (representatively 500 to 1500 Å). Also, if regions 803 between the arbitrary dot patterns are w<sub>pa,1</sub>, w<sub>pa,2</sub>, w<sub>pa,3</sub>, ..... w<sub>pa,m</sub>, W<sub>pa</sub> is represented by the following expression.

[EXPRESSION. 2]

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expansion of the drain side depletion layer cannot be restrained.

For the above reasons, it is desirable that the relational expressions of  $W_{pa}/W$  and  $W_{pi}/W$  fall into a range of 0.1 to 0.9 (preferably 0.2 to 0.8), and also  $W_{pi}/W_{pa} = 1/9$  to 9 is satisfied. It should be noted that if the channel length is  $L$ , a channel formation area is represented by  $W \times L$ .

Also, the present invention is effective in an improvement of the mobility that is a representative parameter which exhibits the performance of an FET. The reason will be described below.

The mobility is determined in accordance with the scattering of carriers in a semiconductor (a silicon substrate in this embodiment), and the scattering in the silicon substrate is roughly classified into the lattice scattering and the impurity scattering. The lattice scattering is controllable at a low impurity concentration in the silicon substrate and at a relatively high temperature, and the impurity scattering is controllable at a high impurity concentration and at a relative low temperature. The entire mobility  $\mu$  obtained by influencing them with each other is represented by the following expression.

[EXPRESSION. 5]

$$\mu = (1/\mu_l + 1/\mu_i)^{-1}$$

The expression 5 means that the entire mobility  $\mu$  is reversely proportional to a sum of the inverse number of the

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increased because of an influence of the impurity scattering. However, in the present invention, since the impurity regions are locally formed, no impurity is added between the adjacent impurity regions (a region having a width of  $W_{pa}$ ).

In other words, because the expression 7 logically means that the concentration  $N_i$  of impurities of the ionized impurities approaches 0 without limit, the mobility  $\mu_i$  approaches infinite without limit. In other words, the expression 5 means that the impurities are reduced to the degree that a term of  $1/\mu_i$  can be ignored, the entire mobility  $\mu$  approaches the mobility  $\mu_1$  without limit.

Also, it is logically possible that the effective mass ( $m^*$ ) of the carriers is reduced so that the mobility  $\mu_1$  is further increased. This is performed by employing a phenomenon by which the effective mass of the carriers (in particular, in case of electrons) is changed depending on the axial direction of a crystal axis in a region of an extremely low temperature.

According to the literature, when it is structured such that a channel direction connecting between the source and the drain (a direction along which carriers are moved) is identical with  $\langle 100 \rangle$  axial direction of a monocrystal silicon, the minimum effective mass can be obtained.

For example, as shown in Fig. 15, it is assumed that a monocrystal silicon substrate 1501, a source region 1502 a

channel forming region 1503 and a drain region 1504 are formed on a monocrystal silicon substrate 1501 having a (100) face. In this situation, a case in which a channel direction 1505 is [100] corresponds to this example. This example is a result in a region of an extremely low temperature of 4°K.

Also, it is desirable that the channel direction and the axial direction (arranging direction) of the impurity region 707 are made substantially in parallel with the axial direction of the crystal lattices (an axial replacement is within  $\pm 10^\circ$ ) so that the carriers well move between the crystal lattices. In case of monocrystal, since the silicon atoms are regularly arranged, the carriers which move in parallel to a direction along which the crystal lattices are arranged are hardly influenced by the scattering of the lattices.

For example, if the rotating axis in the above direction in the monocrystal silicon substrate is  $0^\circ$ , then in case of the rotating axes of  $90^\circ$ ,  $180^\circ$  and  $270^\circ$ , the same effect can be obtained.

As described above, the carriers that move in the channel forming region pass through a region other than the impurity regions which exist within the channel forming region. This appearance will be briefly described with reference to a schematic diagram of Figs. 16A to 16C.

In Fig. 16A, reference numeral 1601 denotes a channel forming region. In other words, Fig. 16A is a diagram showing

the channel forming region viewed from an obliquely right top. The channel forming region according to the present invention has an impurity region 1602 as shown in Fig. 16A, three-dimensionally.

An arrow 1603 shown in Fig. 16A denotes a progressive direction of the carriers (electrons or holes). As shown in Fig. 16A, a plurality of impurity regions 1602 are disposed within the channel forming region 1601, and the carriers pass through a region other than those impurity region 1602.

The progressive direction of the carriers looks as shown in Fig. 16B when being viewed from the top surface of the channel forming region 1601. Fig. 16B is a diagram showing a surface indicated by ACEF in Fig. 16A. It is understandable from Fig. 16B that the carriers move in a region having no impurity scattering while avoiding the impurity regions 1602.

In other words, as indicated by the arrow, most of the carriers go between the impurity regions 1602 and move between the source and the drain. It is needless to say that the carriers move zigzag such that they avoid the impurity regions.

Also, what is shown in Fig. 16C is a diagram viewed from a side surface of the channel forming region 1601. Fig. 16C is a diagram showing a surface represented by ABCD in Fig. 16A. What is denoted by reference numeral 1603 is an arrow which is directed toward this side from the paper. It is

understandable from the figure that the carriers move between the impurity regions 1602.

(Embodiment 2)

In this embodiment, there is shown an example of structuring a CMOS circuit with a complementary combination of an n-channel FET (NMOS) and a p-channel FET (PMOS) in accordance with the present invention. Although the details of a process of manufacturing the CMOS circuit will be omitted here, the impurity regions shaped in a dot pattern is formed only in the channel forming region before forming the gate insulating film according to the present invention, as was described in the embodiment 1.

Fig. 13A shows a cross-sectional view of a CMOS circuit in accordance with the present invention. Fig. 13A is a cross-sectional view of the CMOS circuit cut along the channel direction, which is formed through a normal manufacturing method.

In Fig. 13A, reference numeral 1301 denotes an n-type silicon substrate, reference numeral 1302 denotes a n-well, and reference numeral 1303 denotes a p-well. In other words, a p-channel FET (PMOS) is formed on the n-well 1302, and an n-channel FET (NMOS) is formed on the p-well 1303.

The NMOS and PMOS are divided by a field oxide film 1304 which has been formed through the selective oxidizing method, respectively, and a channel stopper 1305 is disposed under the p-well side field oxide film.

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Also, impurities that give p-type conduction, for example, boron is added to the n-well 1302 so that a source region 1306 and a drain region 1307 of the PMOS are disposed. Further, impurities that give n-type conduction, for example, phosphorus or arsenic is added to the p-well 1303 so that a drain region 1308 and a source region 1309 of the NMOS are disposed.

In the channel forming regions interposed between the source region 1306 and the drain region 1307, and between the source region 1308 and the drain region 1309, respectively, impurity regions 1311 and 1312 shaped in a dot pattern are formed in advance before forming a gate insulated film 1310.

The reason why the impurity regions 1311 and 1312 are formed before formation of the gate insulating film 1310 in this embodiment is to prevent an interface between the gate insulating film 1310 and the channel forming region from being damaged. However, a method of adding the impurities through the gate insulating film 1310 can be applied.

It should be noted that since oxygen is used in formation of the impurity regions 1311 and 1312 in this embodiment, the NMOS and the PMOS are made common without a necessity of distinguishing the NMOS and the PMOS.

Also, in the case of the CMOS circuit as in the present invention, it is desirable that the impurity regions 1311 and 1312 are formed even within the drain regions 1307 and 1308 as shown in Fig. 13A.

When the semiconductor device of the present invention is used, for example, for a device such that the source and the drain are exchanged as in a pixel, impurity regions may be formed in both of the source region and the drain region.

Then, gate electrodes 1313 and 1314 which are made of a conductive material are formed on the channel forming region, and an interlayer insulation film 1315 is formed to cover those gate electrodes 1313 and 1314. Furthermore, contact holes are defined in the interlayer insulating film 1315 so that a source electrode 1316 of the PMOS, a common drain electrode 1317 of the PMOS and the NMOS, and a source electrode 1318 of the NMOS are disposed.

Since the CMOS structure having a structure shown in Fig. 13A can be fined without suffering from a problem such as the short channel effect in accordance with the present invention, an integrated circuit extremely high in the degree of integration can be structured.

Also, there can be structured a BiCMOS circuit made up of the combination of the CMOS circuit shown in Fig. 13A and a bipolar transistor. An example of the BiCMOS circuit formed in accordance with the present invention is shown in Fig. 13B.

In Fig. 13B, reference numeral 1319 denotes a p-type silicon substrate, reference numeral 1320 denotes an embedded n<sup>+</sup> region, and reference numeral 1321 denotes a p-well formed through the epitaxial growth. A p-well 1321 on the embedded n<sup>+</sup> region 1320 is doped into n-type conduction to form an n-



well 1322 that functions as a collector. Also, reference numeral 1323 denotes a deep n<sup>+</sup> region that forms a take-off electrode from the embedded n<sup>+</sup> region 1320.

Reference numeral 1324 denotes a field oxide film formed through a normal selective oxidizing method. An n<sup>+</sup> region 1325 is formed on the p-well 1321, and a p<sup>+</sup> region 1326 is formed on the n-well region 1322. On the n-well 1322 on a side where the bipolar transistor is structured, there is first formed a p<sup>-</sup> region 1327 that forms an active base, and there are then arranged a p<sup>+</sup> region 1328 and an n<sup>+</sup> region 1329.

It should be noted that an impurity region 1330 is arranged on both of the PMOS side and the NMOS side. The impurity region 1330 may be formed after the n<sup>+</sup> region and the p<sup>+</sup> region have been formed, or before they have been formed. It is needless to say that any one of carbon, nitrogen and oxygen may be used.

Then, a gate electrode 1331, and interlayer insulating film 1332, and a source/drain wiring 1333 are disposed to structure a BiCMOS circuit. The BiCMOS circuit is structured to effectively use the high-speed operability of the bipolar transistor and the low power consumption property of the CMOS circuit together.

(Embodiment 3)

In the embodiment 1, a depthwise shape of the impurity region 707 is shaped in a bar. However, this is a shape under an ideal state where no scattering occurs when implanting



can be provided. In this example, since there is structured so that gaps between the dot patterns are supplemented by a next row, a lateral expansion of the drain side depletion layer can be effectively prevented. In particular, it is very effective in the IG-FET such that the influence of the short channel effect becomes extremely large as in the case where the channel length is  $0.1\ \mu\text{m}$  or less.

However, since a path along which carriers move is meandered as indicated by a dotted line, there is a possibility of lowering the mobility as much as a distance of the movement of carriers is increased. However, in a region where the channel length is  $0.1\ \mu\text{m}$  or less, at which this structure exhibits the effect, since the carriers going out of the source region reach the drain region in an instant, it is considered that there arises no problem even if the moving distance is somewhat increased.

Hence, it is desirable that in the case where the channel length is, for example,  $0.1\ \mu\text{m}$  or longer, the impurity regions shaped in a dot pattern are disposed as shown in Fig. 1A, and in the case where the channel length is  $0.1\ \mu\text{m}$  or shorter, they are disposed as shown in Fig. 10A.

Also, as shown in Fig. 10B, the dot pattern can be shaped in an ellipse or a rectangle which are perpendicular to the channel direction. In this example, it is structured to be suitable to restrain the drain side depletion layer. However, because there is a possibility of obstructing the

movement of carriers, it is preferable that the structure is applied to a semiconductor device which is very short in channel length of, for example, 0.2  $\mu\text{m}$  or shorter.

Further, as shown in Fig. 10C, the dot pattern can be shaped in an ellipse or a rectangle which are in parallel with the channel direction. In this example, since it is structured such that the narrow channel effect is more remarkably exhibited, it is effective to increase the threshold value voltage somewhat when required.

(Embodiment 5)

The present invention is applicable to not only the lateral IG-FET as described in the embodiment 1, but also IG-FETs of various structures. For example, the lateral IG-FET may have other structures such as an LDD (offset) structure (Fig. 11A), a double-drain structure (Fig. 11B), an embedded channel structure (Fig. 11C), an SOI structure (Fig. 11D), an SIMOX structure (Fig. 11E) or the like.

In this embodiment, a case in which an n-channel FET is applied to the above structure as an example will be described. In the figure, N+ and N- represent the relative strength of the n-type conductivity, and N+ means the n-type conductivity stronger than N-.

Fig. 11A shows a structure in which a low-density impurity region 1103 is disposed between a source or drain region 1101 and a channel forming region 1102. Although the drain side depletion layer is liable to gently expand because

the low-density impurity region 1103 exists, the present invention can restrain its expansion.

Also, Fig. 11B shows a structure in which conductive regions 1105 having a width of 0.1 to 0.5 $\mu$ m are formed on both sides of a source or drain region 1104. The source or drain region 1104 is identical in conductivity with the conductive region 1105, and the conductive region 1105 is weaker in conductivity than the source or drain region 1104. For example, As (arsenic) is implanted to form the source or drain region 1104, P (phosphorus) is implanted to form a weak conductive region 1105.

There is many cases in which the embedded channel structure shown in Fig. 11C is formed resultantly when a CMOS circuit is structured by an n-channel FET and a p-channel FET, and such a structure is liable to be influenced by the short channel effect.

Structurally, for example, in the n-channel FET, a conductive region 1107 which is identical in conductivity with and weaker in conductivity than the source/drain region 1106 is formed in the vicinity of an interface of the channel forming region.

Therefore, a channel is formed immediately below the conductive region 1107, and similarly in this case, the present invention is implemented with the results that the short channel effect can be restrained, and the punch-through

phenomenon and the deterioration of the threshold value voltage can be prevented.

Further, since the SOI structure is of a technique which has been developed with a purpose of thinning the semiconductor layer which is used as a device to reduce the depletion layer, the SOI structure per se provides the effect of restraining the short channel effect. For example, the structure shown in Fig. 11D is generally called "SOS (silicon-on-sapphire) structure", which is formed by allowing silicon monocrystal to grow on a sapphire substrate 1108.

However, it is difficult to form a monocrystal silicon layer of 1  $\mu\text{m}$  or less, and there is a limit of restraining the expansion of the depletion layer. Therefore, if the present invention is applied to the SOI structure, it is possible to more surely prevent the short channel effect.

An example in which an IG-FET is formed on a substrate which is generally called "SIMOX (separation-by-implanted oxygen) although it belongs to the above-mentioned SOI structure is shown in Fig. 11E. In this example, oxygen is implanted into a monocrystal silicon substrate 1109, to thereby form an embedded oxide layer 1110. Also, a depth of implantation of oxygen is made shallow, thereby being capable of forming a monocrystal thin film which is extremely thin.

Even in the above example, the present invention is applicable thereto. In this case, there can be expected such

an effect as to restrain (pin) the expansion of the drain side depletion layer toward the channel forming region.

(Embodiment 6)

In the present invention, as a means for forming an impurity region in the channel forming region, there can be applied a method of employing a property that impurities are segregated by a distortion, other than a method of patterning with a resist mask.

First, a state identical with that shown in Fig. 7B is obtained in accordance with a process described in the embodiment 1. In other words, in Fig. 12A, reference numeral 1201 denotes a silicon substrate, reference numeral 1202 denotes a field oxide film, and reference numeral 1203 denotes a channel stopper.

In this state, an anisotropic etching process is conducted locally on the surface of a silicon substrate by using a convergent ion beam or the like, to thereby draw a groove-like or hole-like pattern 1204 in a desired shape at a desired position (Fig. 12A).

Then, impurity elements, for example, nitrogen is added on the entire surface of the substrate 1201. It is needless to say that nitrogen may be replaced by carbon or oxygen. The impurity elements are used to form impurity regions later. Also, it is desirable that a depth of implantation is deeper than the groove-like or hole-like pattern 1204 (Fig. 12B).

After completion of addition of the impurity elements, a heat treatment is conducted at a high temperature of about 1000 to 1200 °C. Through this heat treatment, a heat oxide film is formed on both side walls of the groove-like or hole-like pattern 1204 so that the groove-like or hole-like pattern 1204 is embedded. Therefore, this region substantially comes to an oxide region 1205 as represented by  $\text{SiO}_x$ . In this case, it is preferable that the heat treatment is conducted in an oxidation atmosphere because a rate of forming the oxide region 1205 increases.

Then, the impurity elements which have been added to the entire silicon substrate 1201 simultaneously is segregated to the oxide region 1205. This is because the impurity elements are segregated by a large distortion, a lattice defect or the like which occurred in the vicinity of the oxide region.

Through the above process, the impurity elements are segregated to form an impurity region 1206 in the periphery of the oxide region 1205.

Also, in the case where the impurity elements that give one conductivity such as phosphorus or boron are added in the monocrystal silicon substrate 1201, there is a tendency that boron is taken in a heat oxide film and phosphorus is piled up to an interface of the oxide film and silicon, in forming the heat oxide film that structures the oxide region 1205.





semiconductor chip is connected to the external through leads 3012. Normally, when the integrated circuit (IC chip) 3005 is viewed, since only the black package 3011 and the leads 3012 can be viewed from the external, the integrate circuit 3005 is completely a black box.

Drawing out the semiconductor chip protected with the package 3011 from the main body, it is structured, for example, as follows. First, an arithmetic operating section (processor) 3014 and a memory section 3015 are disposed on a substrate 3013. Reference numeral 3016 denotes a bonding section where the semiconductor device and the leads 3012 are connected to each other.

The arithmetic operating section 3014 and the memory section 3015 are made up of a variety of circuits including a CMOS circuit, a BiCMOS circuit, a DRAM circuit, an SRAM circuit and the like. The structure of this embodiment as shown in Fig. 15 is characterized in that the arithmetic operating section 3014 and the memory section 3015 are disposed on the same substrate.

When the arithmetic operating section 3014 and the memory section 3015 are arranged to be adjacent to each other as described above, because a delivery of data between the arithmetic operating section 3014 and the memory section 3015 is conducted at a very high speed, it is possible to form a circuit high in operating speed.

Also, since all the circuits as required can be integrated on one chip, it can be expected that the manufacture costs can be remarkably reduced. Furthermore, an arrangement area is reduced with the result that the product can be downsized.

Since, according to the present invention, the semiconductor device can be fined without suffering from a problem such as the short channel effect, the semiconductor electronic equipment can be further downsized and made portable with being used as the above-mentioned one chip.

(Embodiment 8)

The present invention can be applied to a variety of semiconductor electronic equipments other than the example described in the embodiment 7. This is because the electric characteristics of the semiconductor device according to the present invention are very excellent, and the IC circuit structured using that semiconductor device can realize a high frequency characteristic.

The device characteristic of the single semiconductor device formed according to the present invention is very excellent, and the threshold value voltage  $V_{th,n}$  of the n-channel FET and the threshold value voltage  $V_{th,p}$  of the p-channel FET can be adjusted within a range of -0.5 to 3.0 V and within a range of -0.3 to 0.5 V in accordance with a required drive voltage, respectively. Also, the S-value as



can be satisfactorily applied to the high-frequency IC circuit of this type.

As was described above, the present invention can prevent the short channel effect caused when the channel length becomes short. In particular, first, the expansion of the drain side depletion layer to the source region or the channel forming region is blocked by the impurity regions which are locally formed in the channel forming region so that the drain voltage is not influenced by the energy (potential) state of the channel forming region. As a result, it is possible to prevent the punch-through phenomenon and the deterioration of the sub-threshold characteristic. Also, a high drain withstand voltage can be realized, simultaneously.

Further, the deterioration of the threshold value voltage which is one feature of the short channel effect can be restrained by an increase of the threshold value voltage which is caused by the narrow channel effect. The narrow channel effect is an effect which is artificially performed by the structure of the present invention that the impurity regions are locally formed in the channel forming region.

As was described above, according to the present invention, even in the semiconductor device in the deep sub-micron region which is short in channel length, operation can be conducted without leading to the short channel effect. In other words, the semiconductor device represented by the IG-

FET is hopefully further integrated and improved in performance.

The foregoing description of preferred embodiments of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The embodiments were chosen and described in order to explain the principles of the invention and its practical application to enable one skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto, and their equivalents.